RF Knock Out (RFKO) method

1. Terminology

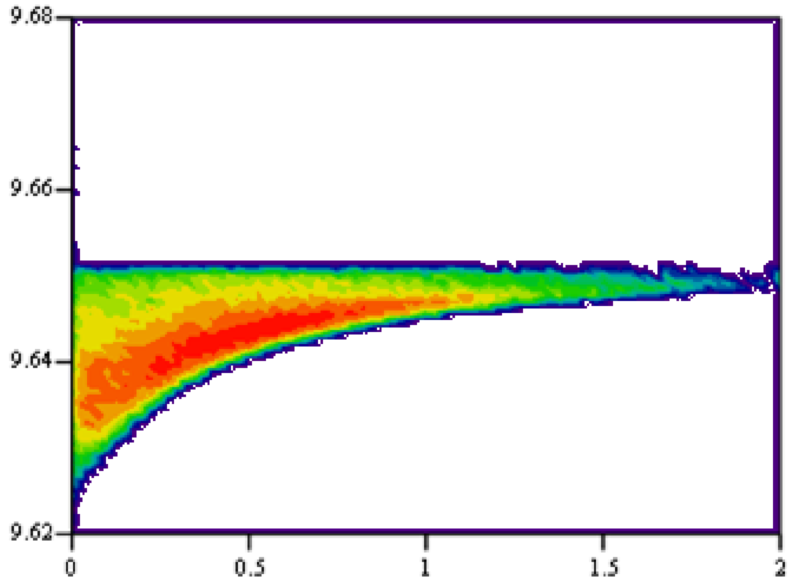
2. Why heating the beam?

3. What is RFKO

Tune vs Action w/Space Charge

(3rd Integer)

Max tune shift, ΔQ_{SC}

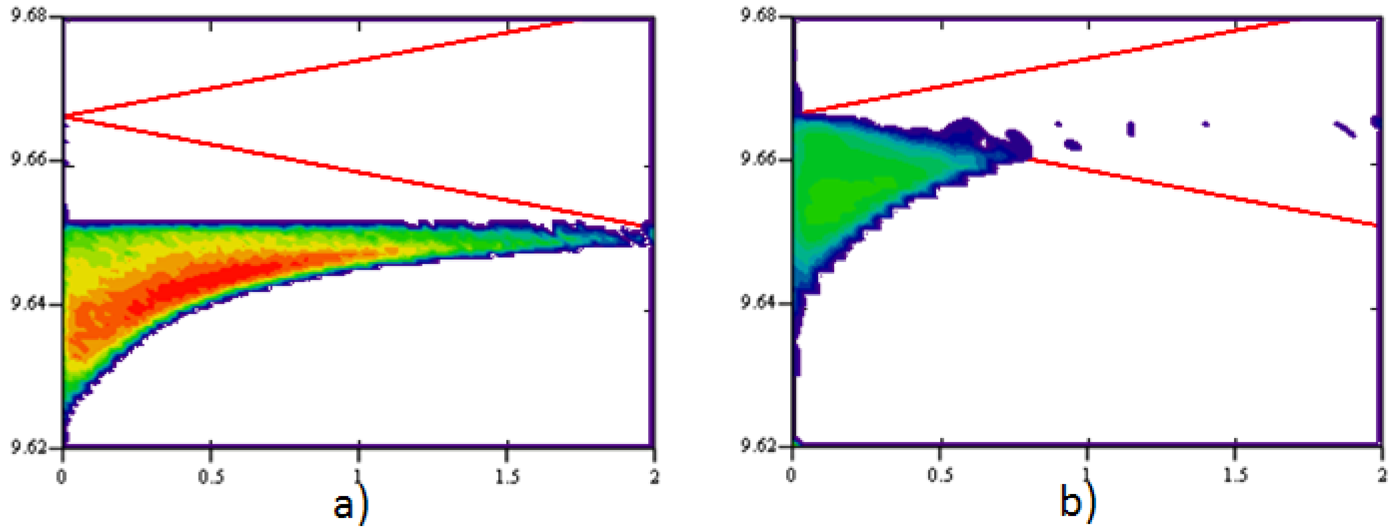


Laslett:

$$\Delta Q_{SC} = \frac{N_p \cdot r_p \cdot BF}{4\pi \cdot \gamma^2 \varepsilon_{rms}^{norm}}$$

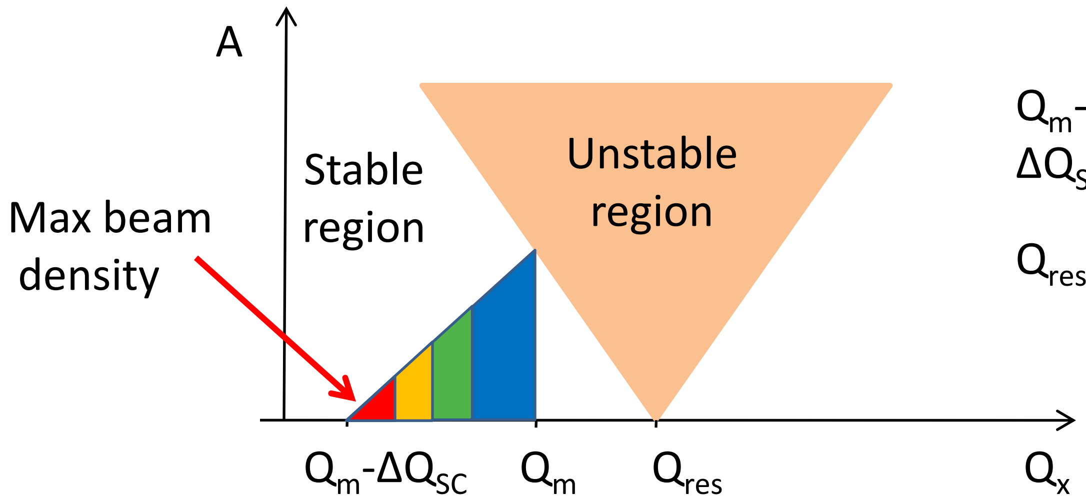
Spread due to J_y

Resonant extraction w/ Space Charge



Tune/Action diagrams wrt the separatrix boundaries

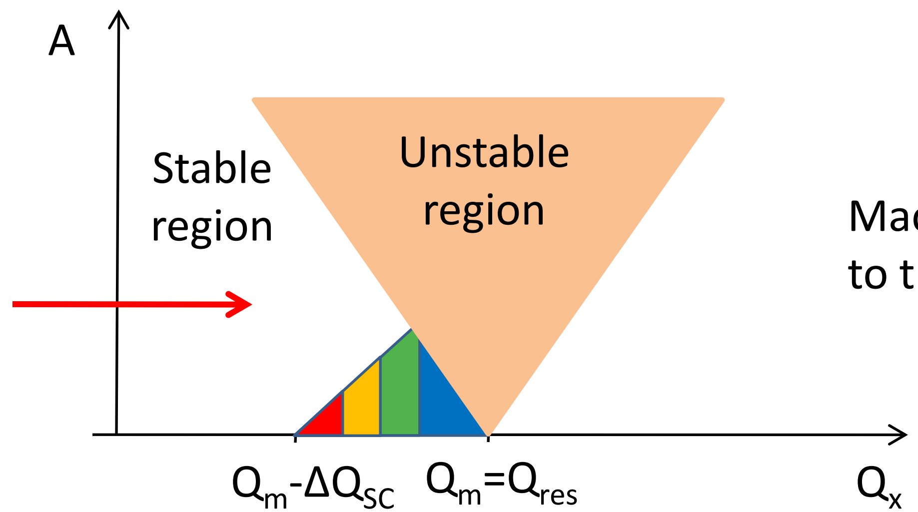
Steinbach's diagrams



Q_m- machine tune
ΔQ_{SC} – SC tune shift

Q_{res}- m/3 resonance

It's tricky to make the spill uniform in a controlled way here using the tune ramp



Machine tune ramped to the resonance

3^{rd} Integer Resonance extraction w/Space Charge

1. We would like to have to have additional handle to control the spill rate in order to make it more uniform

2. Although in theory 3^{rd} integer resonance is capable to remove all the particles, it is practically very challenging to achieve a high level of extraction for particles with small betatron amplitudes

How can we heat the beam:

in X only

fast enough

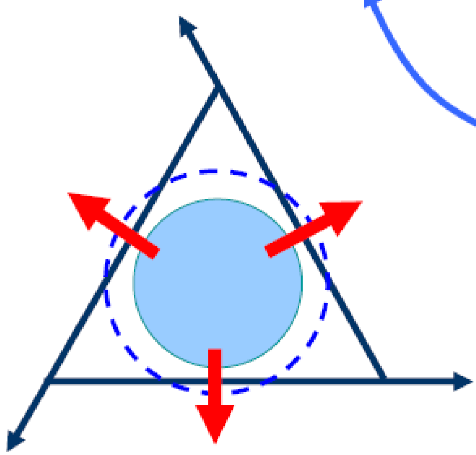
in a controlled way?

RF-KO-SE

NIRS HIMAC

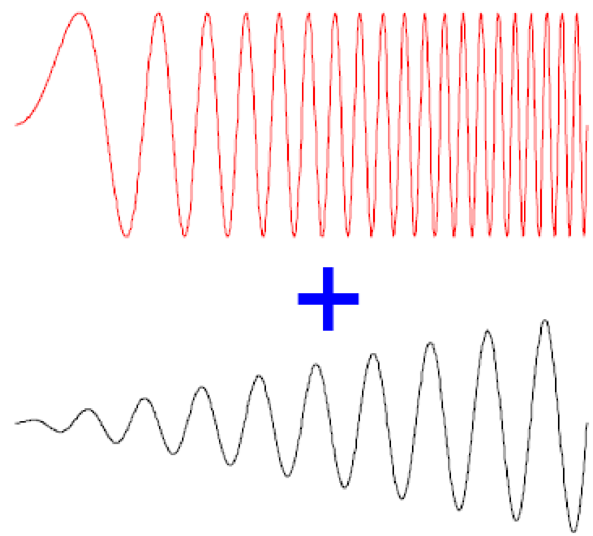
RF-knockout extraction (1)

Diffusion by ***transverse RF-field***



- Constant separatrix
- Fast response of beam on/off
- Easy operation

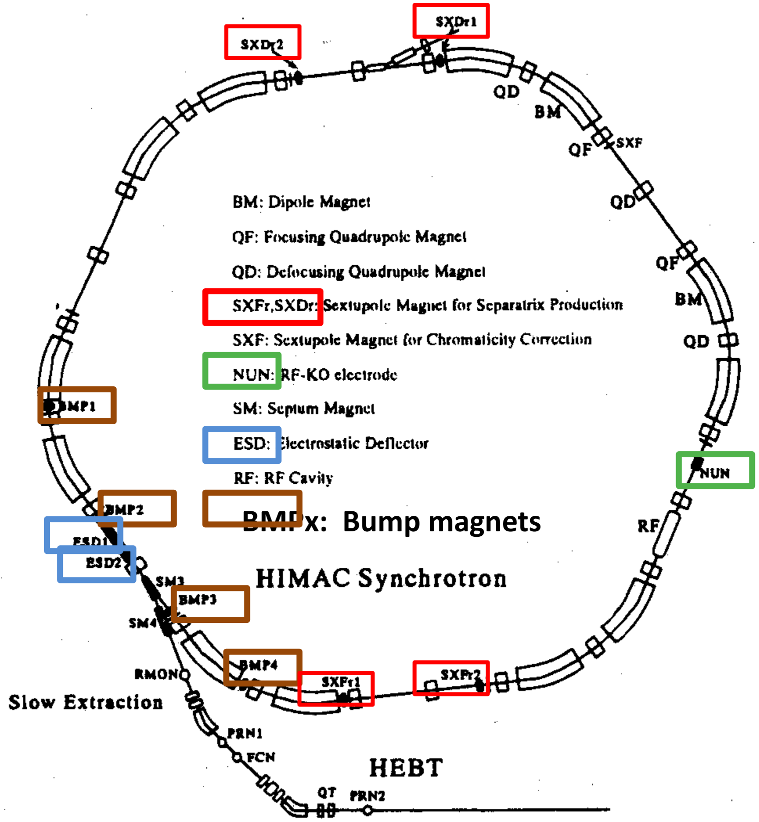
Frequency modulation (FM)

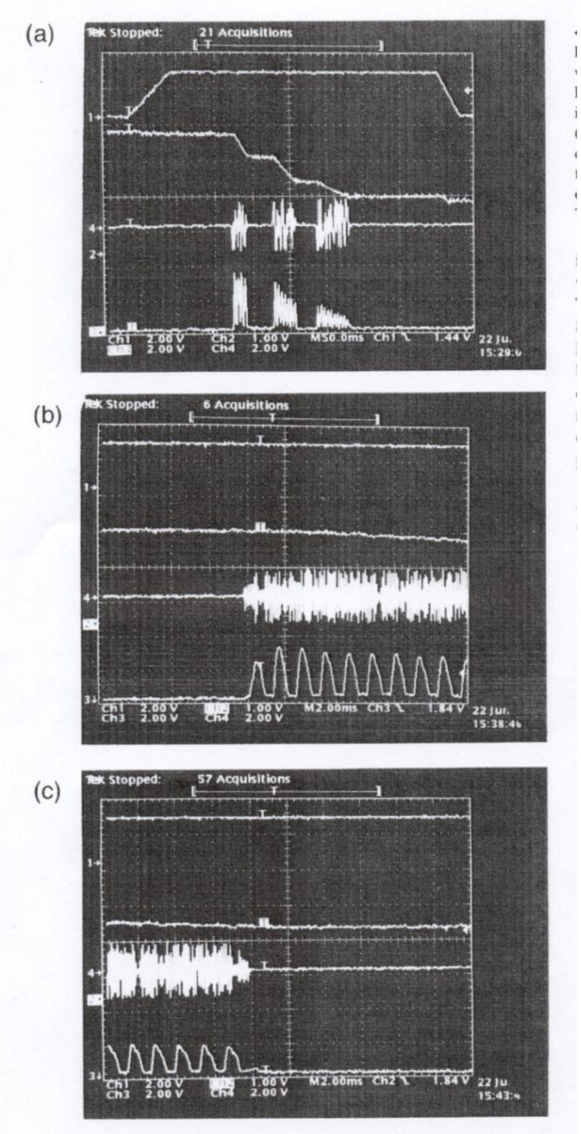


Amplitude modulation (AM)

HIMAC (Heavy Ion Medical Accelerator in Chiba)

Beam: C^{6+}, 290 *MeV/n*



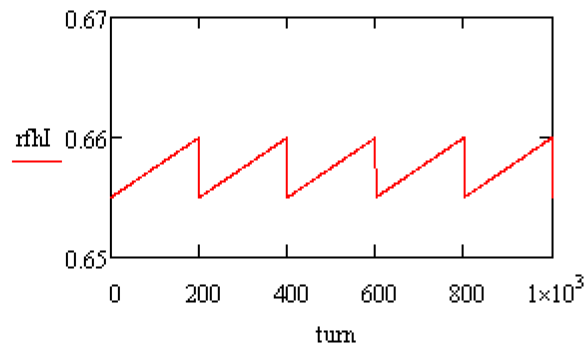


Spill modulation in HIMAC:
on/off time ~1msec

RF frequency modulation

$$rf\_phase = 2 \cdot \pi \cdot f(t) \cdot t = 2 \cdot \pi \cdot q(n) \cdot n$$

$$q(n) = q_0 + \delta q \cdot \left(\frac{\mathrm{mod}(n, N_{sw})}{N_{sw}} - 0.5 \right)$$



Optimal sweep time $\quad N_{sw} \propto \frac{1}{\Delta Q}$

Strong phase correlations effectively blow up the frequency width

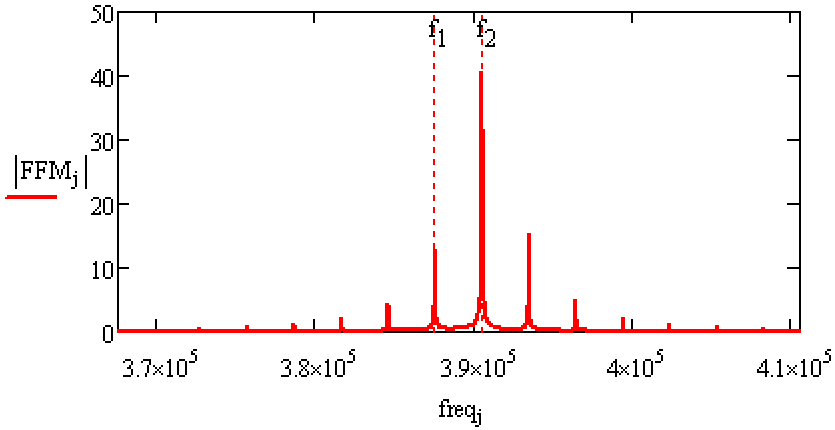
Doesn’t work this way!!!

RF frequency modulation 2

Cure #1: get rid of the “j” increment in the excitation waveform:

$$j \cdot T_{sw} + t \rightarrow t$$

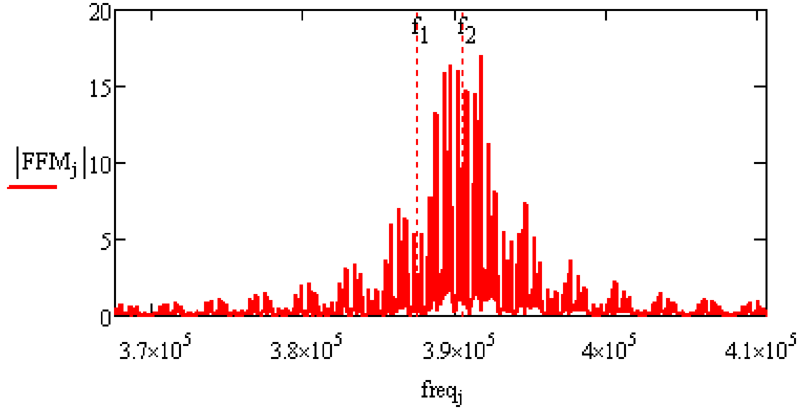
This effectively limits the frequency span, but creates narrow bands, separated by exactly δq:



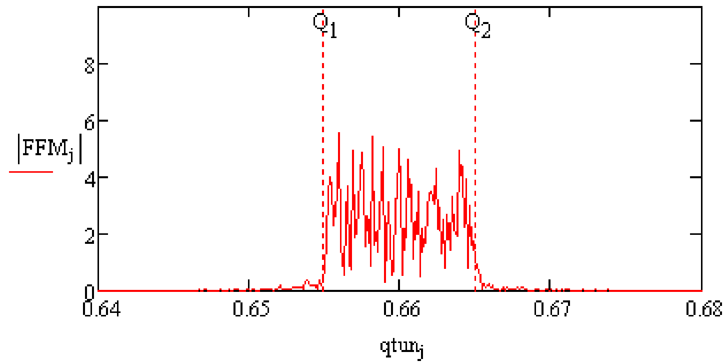
Doesn’t work either!!!

RF frequency modulation 3

Cure #2: add random phase after each sweep:



Another option would be to generate a random noise in given bandwidth:



Both acceptable!

Modeling feedback:

Algorithm:

1. Keep RF power (RFP) low when spill rate (SR) is sufficient
2. Increase RFP by factor FU if SR is low and not growing
3. Reduce RFP by factor FD when SR reached nominal

- Parameters FU, FD are optimized by performance
- Algorithm performs reasonably, but there is room for improvements
- Max RFP in simulations limited to 10kV

Hardware available:

Old TeV-style damper kicker,   gap=6.35cm; L=140cm; stored at F0;   Free

Drive: 2x800W Amps (*Amplifier Research*); 0.01-3MHz; 12.4kV;   56.7 k$

Twice more Watts for 3xPrice

Summary:

1. RFKO AM modulation as an effective intensity control and it can be used in the spill feedback system.
2. FM modulation is important to ensure that all the particles are affected by RF-KO. It is especially important in the case of large SC tune spread.
3. May provide a tool for smoothing spill modulations from machine variations like tune ripple, etc.
4. The extraction scheme with staying at or close to the resonance is advantageous for achieving good extraction efficiency.
5. In our simulations RFKO efficiency is not nearly that of HIMAC due to large tune spread, however proved to do very well for spill rate control.
6. A lot of room for optimizing the method is still available.